REMARKS

Summary of Amendments

By this Amendment, the title, abstract, specification and claims have been revised to adopt the American-style spelling of the word "stabilize" and its variants as required by the Examiner. Also, sections headings have been added to the specification in accordance with U.S. practice.

It is believed that the objections to the disclosure and claims have been overcome.

Also, by this Amendment, Claim 31 has been amended into independent form by incorporating the subject matter of the Claims 1 and 19 from which it depends. Claims 1-35 remain pending in the application.

Allowable Claims

Applicants acknowledge with thanks the indicated allowability of dependent Claims 31 and 32.

Claim 32 depends from Claim 31, and, as noted above, Claim 31 has been amended into independent form. Accordingly, it is believed that Claims 31 and 32 are in a condition for allowance.

35 U.S.C. ¶102 and ¶103

Claims 1-18, 26-28 and 33-35 were rejected under 35 U.S.C. ¶102 or ¶103 as being unpatentable over Kawasaki et al., taken alone or in combination with Sandinsky or Leiphart, for the reasons stated at pages 2-5 of the Office Action. Applicants respectfully traverse this rejection.

This invention relates to the stabilization of the plasma in a plasma processing tool, e.g., formed by radio frequency power, when changes in process conditions occur. It has been discovered that the need for stabilization arises because when a plasma process tool is operated in a manner where gas types are changed or gas pressures are changed or power supplied to the plasma changes, etc., the plasma impedance changes and the efficient coupling of radio frequency power into the plasma is reduced until a matching unit between power supply and plasma can be adjusted to compensate for the impedance change.

The prior art describes the use of impedance matching units locate between RF power supplies and plasma generating equipment in order to match the impedance of the plasma to the, typically 50 ohm, output impedance of the power supply. These matching units are frequently designed so that the matching elements, capacitors or inductors are set to suitable values to allow the plasma to

be struck, and then are allowed to re-adjust value according to feedback signals received from an impedance monitoring device.

These systems generally work very well if plasma processing conditions are not required to change throughout the duration of the process. However, when a significant change is required to occur, for example when switching between different types of process gas for succeeding steps of the process, perhaps with each at different pressures or with different RF powers supplied in each step, the matching unit may require a significant amount of time to be driven to the new optimum matching position under the control of the feedback signal from the impedance monitoring device. If a switched process (alternating etch and deposition steps) is required to etch a feature in a silicon wafer or other workpiece, then it is likely that the impedance of the plasma will be significantly different in each step, because different gases are used at different pressures, with different levels of power supplied to the plasma. If each step lasts only a few seconds, but the time to adjust the matching unit to obtain optimum impedance for each step takes of the order of a second, then it is clear that efficient matching of RF power into the plasma will only occur for a fraction of each step, leading to a very inefficient process. In the extreme case when the length of either or both processing steps is similar to the time for re-matching of the impedance to occur, then the process may be rendered totally useless. In some instances when the

matching unit cannot be readjusted sufficiently rapidly at a step change in process parameters, the plasma may be extinguished and require re-ignition, resulting in a loss of process time.

One of ordinary skill readily understands the difference between RF or other forms of electrical power fed to a plasma process tool in order to strike and sustain the plasma, and RF or other forms of electrical power fed to a plasma process tool in order to accelerate ions to the workpiece. In a basic capacitively coupled reactive ion plasma process tool, one source of RF power is used to perform both functions described above, but in all other high density plasma sources, power is provided separately in order to satisfy the two separate requirement of creating the plasma and accelerating the ions to the workpiece.

The invention is generally aimed at process tools utilizing high density plasma sources, primarily inductively coupled plasma sources, ensuring that the plasma is created and continues to be sustained with high efficiency even when process conditions change from step to step. The invention is not aimed at making adjustments to the energy of the ions, accelerated to the workpiece, in successive steps by adjusting impedance matching conditions or power supply output.

Kawasaki et al disclose an apparatus and a process, wherein etching step and deposition step can be carried out alternately. It also teaches that the two alternating steps have different processing parameters with the voltage different in

the two alternating steps. However this is the voltage used to accelerate the ions to the workpiece and has no connection with the voltages and currents used to generate the plasma. As far as can be ascertained, the plasma formed in the processing apparatus utilizes the same gas mixture and same plasma creation power (supplied by the ecr [electron cyclotron resonance] source) throughout the process of alternating steps. There is therefore no reason why the power fed to the apparatus to create and sustain the plasma should need any adjustment of a relevant impedance matching network (box) throughout the process (after perhaps some initial adjustment immediately after the plasma is initially struck).

The presently claimed invention stabilizes the plasma in a processing apparatus when the switching between steps results in some change in the bulk plasma impedance. In Kawasaki et el it can not be seen how the adjustment of the bias voltage used to accelerate ions to the workpiece could have any stabilizing effect on the bulk plasma properties which are determined by the power separately fed to create and sustain the plasma and parameters such as the gas types and chamber pressure.

The Examiner has also commented that "Kawasaki et al further disclose that the plasma generation for the two steps are stabilised by a matching box that consists of a capacitor (col 3 lines 53 to 65 and col 16 lines 19 to 21)". The Examiner is incorrect here in the use of the phrase "plasma generation". It is clear

from the figure and the text that the plasma generation is by means of the ecr source mounted on the top of the process chamber. The matching box referred to in this part of the text and in the figure is clearly for matching the impedance of the power supply 13 to the wafer support electrode so that a bias is efficiently created on this electrode to accelerate ions to the wafer from the stable plasma created by the ecr source.

The Examiner further comments that "As to claim 4, Kawasaki et al teach that the RF power is inductively coupled into the plasma (see Figure 1)". However, it is clear from Figure 1 and the text that the plasma source is an ecr source which acts to pass energy to electrons in the plasma by a resonance effect for a given applied frequency of radiation typically 2.45 GHz and local value of magnetic field typically 875 gauss. This is not the same as the operating mode of an inductively coupled plasma in which no local constant magnetic field is required and a frequency related resonance does not occur. Typically inductively coupled plasma sources operate at a frequency of a few to a few 10s of MHz, 13.5 MHz being a standard.

The Examiner has stated that "As to claims 6 to 7, Kawasaki et al teach that the matching box is controlled by electrically such as a controller (col 7 lines 6 to 20, col 15 lines 28 to 32). As to claims 14 and 15, Kawasaki inherently teach that the capacitors are adjusted to different values for each of the steps because the

matching box or matching unit is adapted to control the RF power source". It is agreed that in the prior art the controlling of a matching box may be electrically from a controller (frequently variable capacitors are driven by a DC or stepper motor from some form of stand alone or computer controlled devices). From the text of Kawasaki et al there does not appear to be a statement that the matching box requires any significant adjustment either manually or automatically when the bias voltage is adjusted, by adjustment of the RF power output from the power supply and its application to the wafer support electrode. Since the plasma in the processing equipment is formed by the ecr source, it is not clear that the impedance of the support electrode will change significantly when the bias power is adjusted (it is adjustment of the power fed from the RF generator 13 which determines the bias voltage and ion acceleration energy). The phrase "the matching box or matching unit is adapted to control the RF power source" is not understood because it is standard practice to determine power fed to a system by adjustment of the power output of the generator, not by creating a mismatch between the generator and the load. The presently claimed invention is not directed to control of power supplied to a plasma source by deliberately creating a mismatch between RF power supply and plasma load. Rather, the invention aims is to improve the stability of the plasma in each of the two steps of a switched process.

The Examiner further states that "As to claims 17 and 18, Kawasaki teaches that the positions of the capacitor do not vary between etch and deposition step (Figure 16)". However, one of ordinary skill would understand that the capacitors in the match box, used to match the relevant power supply to create and sustain the plasma in almost every case, require different settings between etch and deposition steps.

The Examiner states that "Kawasaki ... fails to disclose that a motor, which is driven by control signals, drives the matching unit. However, Sadinsky discloses a method wherein RF power is adapted through an impedance matching network, that comprises capacitors and are driven by motor for proper adjustment and furthermore the motor is driven by a signal generator (col 3 lines 28 to 34 and, line 60 to col 4 line 5). Therefore, it would have been obvious to one skilled in the art at the time of claimed invention to employ Sadinsky's teaching into Kawasaki et al's method for proper adjustment of the capacitors in the matching unit as taught by Sadinsky".

It is accepted that a matching unit can include variable capacitors as shown in Figure 2 of Sadinsky. Column 4 lines 3 to 5 states with reference to Figure 2 "Capacitors 14 and 18 may be manually adjusted or can be motor driven". This is accepted as again being prior art. The description of the prior art in Sadinsky refers to the basic operation of a matching unit using variable capacitors (which

may be motor driven) in order to match the impedance of an RF power supply to a load. It makes no reference to the need to make adjustments to the impedance matching for each step of a two step (switched) process. It is certainly not obviously taking Kawasaki et al, in which the plasma generation conditions are not changed during the switched process (only the ion accelerating voltage), and therefore plasma impedance would not be expected to change from step to step, in conjunction with Sadinsky, in which a basic variable capacitor based impedance matching unit is described as prior art, to reach the conclusion that pending claims 11 and 12 are unpatentable in the form in which they are dependent on preceding claims.

It should be noted that the patent of Sadinsky describes the design of an impedance matching network which does not use variable capacitors at all and instead uses adjustable inductors. The reference to variable capacitors is simply in the description of prior art.

The Examiner also states that "Kawasaki ... fails to disclose that a further gas can be introduced into the chamber to stabilise the plasma. However, Leiphart teaches that the introduction of an inert gas such as argon or any noble gas can be used into the chamber to stabilise the plasma (col 10 lines 66 to col 11 lines 4). Therefore, it would have been obvious to one skilled in the art at the time of

claimed invention to employ Leiphart's teaching into Kawasaki's method for stabilising the plasma as taught by Leiphart".

Leiphart refers to the introduction of argon into the sputter deposition tool described in the patent because argon is the most widely used gas in sputtering tools because of its high sputter efficiency. Reference is made to other noble gases because they are to be preferred over reactive gases because they do not become incorporated in sputtered films. The text simply refers to the normal start up procedure for a plasma processing tool. Gas is introduced and the plasma is struck and allowed to stabilise for a period of time. There is no indication in the text of Leiphart that the argon is being used as a buffer gas during a switched process and all evidence points to it being the sole process gas used in an unswitched sputter process.

As has already been indicated, Kawasaki et al describes a process tool in which a stable plasma of a constant gas mixture is operated (switching between etch and deposition steps being achieved by adjustment of the ion energy). It is not at all obvious why taking Kawasaki et al with Liephart, where the description is of simply turning on the plasma in a sputter etch system could ever lead one skilled in the art to consider the use of a buffer gas during the switching between an etch and deposition gas in a switched process utilising different gases, pressures, plasma creation powers etc in each step.

For at least the reasons stated above, Applicants respectfully contend that Claims 1-18, 26-28 and 33-35 are neither anticipated by nor obvious in view of the teachings of Kawasaki et al., taken alone or in combination with Sandinsky or Leiphart.

35 U.S.C. ¶102

Claims 1-5, 19-25, 29-30 and 33-35 were rejected under 35 U.S.C. ¶102 as being unpatentable over Okudaira et al. for the reasons stated at pages 3-4 of the Office Action. Applicants respectfully traverse this rejection.

The Examiner states that "Okudaira et al disclose a process wherein etching and deposition is performed alternately into a reaction chamber at predetermined time intervals. Okudaira et al also disclose that at least etching gas and the deposition gas are supplied alternately and for a certain period of time etching gas and deposition gas can be supplied simultaneously and continuously (col 2 lines 41 to 49 and Figures 1 and 3)". It is agreed that the alternate supply of etching and deposition gas is well known in the prior art. Figures 1 and 3 show etching and deposition gases being supplied alternately with no overlap (simultaneous supply of both gases). There is however no reference in the text to deliberate overlapping of the supply of the two gases with the purpose of reducing rapid changes of pressure within the process chamber which could lead to plasma instability.

The Examiner also comments that "Okudaira et al further disclose that the intensity of the power is controlled by an impedance matching circuit for compensating the high frequency power supply (col 5 lines 15 to 17)".

The text of Okudaira et al states "An impedance matching circuit is provided on the power supply side between the high frequency power supply 9 and the sample stand 6. The on/off control of the high frequency power supply need not always be conducted by turning on/off of the power supply but may be based on power strength control (eg control of the standing wave ratio)." The plasma processing tool described in Okudaira et al utilizes an ecr or microwave system to create the plasma and RF power is used to create the bias which accelerates ions to the wafer or other workpiece. The adjustment of the matching unit between the RF power supply 9 and the sample stand 6 therefore only serves to modify the power fed to the sample stand. It has no effect on the plasma which is created by the microwave source. The presently claimed invention is directed to stabilizing the plasma created within the plasma processing apparatus, not to control the energy of ions accelerated to the workpiece. As a second point, the text of Okudaira et al states that adjustment of the matching unit may be used as an alternative to on/off control of the power supply, which appears to indicate no fine control of power supplied to the sample stand.

Next the Examiner states that "As to claim 19, Okudaira et al teach that the plasma is stabilised by maintaining a reduced pressure of the alternating etching and deposition gas (col 5 lines 38 to 42)". As far as the statement is understood it simply refers to the fact that the process gases are introduced into the processing chamber at a low (reduced) pressure, as is the case in almost all plasma processing equipment (with the exception of equipment designed to operate near or at atmospheric pressure). Figures 1 and 3 indicate steady continuous flow of both etch and deposition gases throughout the respective steps.

Further the Examiner states that "As to claim 20, Okudaira et al teach that deposition gas is supplied before the etching gas is switched off or vice versa (see Figure 3)". A study of Figure 3 provides no basis for this statement. This Figure clearly shows separate steps of 10 seconds duration during which deposition gas is supplied and steps of 3 seconds duration during which etching gas is supplied, with no overlap or gap between steps.

The Examiner comments that "As to claims 29 and 30, Okudaira et al teach that the pressure is monitored and adjusting the flow of the process gases into the chamber during the alternating etch and deposition steps (col 5 lines 38 to 42)". However it is not possible to find any reference to adjustment of gas flows as a result of pressure measurements, in or around the text lines specified.

For at least the reasons stated above, Applicants respectfully contend that Claims 1-5, 19-25, 29-30 and 33-35 are neither anticipated by nor obvious in view of the teachings of Okudaira et al.

Conclusion

No other issues remaining, reconsideration and favorable action upon the Claims 1-35 now-pending in the application are requested.

Respectfully submitted,

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November 12, 2002

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ATTACHMENT "A"

Additions/deletions to paragraphs of the specification:

Page 1, lines 2-6:

This invention relates to a method and apparatus for processing a workpiece in which a plasma struck in the chamber is stabili[s]zed during the transition between steps, particularly, although not exclusively, steps in a cyclic process in the treatment of the workpiece.

Page 2, lines 20-21:

(c) stabili[s]zing the plasma during the transition between the first and second steps.

Bridging pages 2 and 3:

Of course, more than two steps may be used in the treatment of the workpiece. When a cyclic process is used, the plasma is preferably stabili[s]zed between each cyclic step. The method is particularly applicable where a workpiece is treated by cyclically carrying out alternating etch and deposition steps.

Page 3, lines 5-9:

In one embodiment, the plasma may be stabili[s]<u>z</u>ed by matching the impedance of the plasma to the impedance of the power supply which provides energy to the plasma by means of a matching unit. The given method of impedence matching is well known to those skilled in the art.

Bridging pages 3 and 4:

The matching unit may be adjustable manually or electrically, although any suitable method of adjustment may be used. Preferably, when the plasma strikes, the plasma impedance is matched to the power supply impedance automatically for at least a part of the time of treatment of the workpiece. The matching unit may be pre-set to act in time at or just before the transition between the first and second steps, or indeed between all steps where more than two treatment steps are used. For example, in a switched etch/deposition process, the matching unit may be pre-set at or just before the transition between an etch step and a deposition step, or a deposition step and an etch step, in the cyclic process. In such an embodiment, the auto-matching may be re-enabled when the chamber pressure and/or other parameters have stabili[s]<u>z</u>ed. In one embodiment, the automatic matching is disabled at or slightly before the transition. The pre-setting may be determined from a previous step of the same type in a cyclic process.

Page 5, lines 15-25:

As an alternative to, or in addition to, the matching unit described above, the plasma may be stabili[s]<u>z</u>ed by substantially preventing or reducing variation of the pressure in the chamber between the first and second steps. When this is used in relation to a cyclic etch/deposition process, the deposition gas may be supplied, or increased in flow rate, before the etch gas is switched off, or reduced in flow rate, and the etch gas may be supplied, or increased in flow rate, before the deposition gas is switched off, or reduced in flow rate, during the cyclic process.

Page 7, lines 3-13:

The plasma may be stabili[s]<u>z</u>ed by feeding a further gas into the chamber. This "buffer" gas reduces the variation in the pressure from the first to the second step, for example. Thus, in a cyclic etch/deposition process, the buffer gas reduces the variation in the pressure between each etch and deposition step or vice versa. The gas may be fed into the chamber by means of a fast acting flow controller. The "buffer" gas may be any suitable gas, although is typically a noble gas (for example helium or argon), oxygen or nitrogen or a mixture thereof. A preferred "buffer" gas is helium.

Page 8, lines 5-21:

According to a second aspect of the present invention, there is provided a plasma processing apparatus comprising a chamber having a support for a workpiece, means for striking a plasma in the chamber, means for cyclically adjusting processing parameters between a first step and a second step, and means for stabili[s]zing the plasma during the transition between the first and second steps.

The stabili[s]zing means may comprise a matching unit for matching the impedance of the plasma to the impedance of a power supply which supplies power to the plasma. Alternatively, or additionally, the stabili[s]zing means may comprise a means to vary the RF power supply frequency or may comprise means for reducing the variation of the pressure in the chamber between the first and second steps, for example means for feeding a gas into the chamber. This gas is the "buffer" gas described above.

Page 14, lines 6-10:

Thus, in one embodiment, the invention discloses the pre-setting of the matching unit settings at, or just before, the switch from one step to the next, and then re-enabling the auto-match system when chamber pressure and/or other appropriate parameters have stabili[s]zed.

Bridging pages 14 and 15:

In detail, for a two step process involving a deposition step followed by an etch step followed by a further deposition step, a further etch step and then many repetitions of the sequence, it is assumed that the plasma has been struck initially and the description is of an arbitrary stage in the sequence. As the switch occurs to the deposition step, the matching unit settings are driven to pre-determined values that will be close to those required for stable plasma operation in the deposition step. After a period of time, related to the time that the chamber pressure, or other relevant parameter, takes to stabili[s]z̲e, the auto-matching facility is enabled to allow tracking of the plasma impedance. As the end of the deposition step is reached, the auto-matching is disabled and the matching unit settings are set to those required for the etch step. Again, after a pre-set period of time, based on the time that the chamber pressure, or other parameter, takes to stabili[s]z̲e, the auto-matching is re-enabled. The etch plasma impedance is then tracked by the auto-matching facility until the end of the etch step when the auto-matching is again disabled, and the matching unit settings are driven to the values required for the deposition step. The sequence of operations is shown in Figure 2.

ATTACHMENT "B"

Additions/deletions to the claims:

1. (Amended) A method of processing a workpiece in a chamber, the method comprising:

(a) striking a plasma in the chamber;

(b) treating the workpiece by cyclically adjusting the processing parameters between at least a first step having a first set of processing parameters and a second step having a second set of process parameters; and

(c) stabili[s]z̲ing the plasma during the transition between the first and second steps.

2. (Amended) A method according to Claim 1, wherein the plasma is stabili[s]z̲ed between each cyclic step.

5. (Twice amended) A method according to Claim 1, wherein the plasma is stabili[s]z̲ed by matching the impedance of the plasma to the impedance of the power supply which provides energy to the plasma by means of a matching unit.

9. (Amended) A method according to Claim 8, wherein automatic matching is enabled when the chamber pressure and/or other parameters have stabili[s]zed.

19. (Twice amended) A method according to Claim 1, wherein stabili[s]zation of the plasma is enhanced by substantially preventing or reducing variation of the pressure in the chamber between the first and second steps.

26. (Twice amended) A method according to Claim 1, wherein stabili[s]zation of the plasma is enhanced by feeding a further gas into the chamber.

31. (Twice amended) A method [according to Claim 19,] of processing a workpiece in a chamber, the method comprising:

(a) striking a plasma in the chamber;

(b) treating the workpiece by cyclically adjusting the processing parameters between at least a first step having a first set of processing parameters and a second step having a second set of process parameters; and

(c) stabilizing the plasma during the transition between the first and second steps,

wherein stabilization of the plasma is enhanced by substantially preventing or reducing variation of the pressure in the chamber between the first and second steps, and

wherein the chamber is provided with a portion separated from the main part of the chamber by a deflectable member.

33. (Amended) A plasma processing apparatus comprising a chamber having a support for a workpiece, means for striking a plasma in the chamber, means for cyclically adjusting processing parameters between a first and a second step, and means for stabili[s]z̲ing the plasma during the transition between the first and second steps.

35. (Twice amended) A plasma processing apparatus according to Claim 33, wherein the stabili[s]z̲ing means comprises means to vary the RF power supply frequency, or means for reducing the variation of the pressure in the chamber between the first and second steps.